An Age Comparison Study:
Using the Maxilla as an Alternative Age
Determination Method for
Lake Michigan lake trout, *Salvelinus namaycush*

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Abstract

The understanding of fish population dynamics is essential to conservation efforts and the regulation of fishing individual species. The capture of lake trout (*Salvelinus namaycush* Walbaum) and the extraction of calcified structures for age determination are necessary to study changes in the species' populations within the Great Lakes. There are two structures, scales and otoliths, which are widely used for age determination. However, it is well known among fish biologists that scales are largely inaccurate at determining ages in older fish. Studies show that the otolith is the most precise structure for determining age, although it is quite difficult to read and years of experience are required to achieve accurate readings. Recently, a technician in Alpena, MI discovered that thin sections of the maxillary bone, or upper jaw, proved to be much easier to read and just as accurate as the otolith. In this study, I compared ages obtained from scales, otoliths, and maxilla to the true age of the fish from which they were taken, using structures obtained from fish containing coded wire tags (CWTs) and distinct fin clips. Additionally, I created visual comparisons of the accuracy of each structure. I found the maxilla to be a much more accurate structure for age determination in both CWT fish and fin clipped fish. Otoliths were second in accuracy though the reads obtained from them tended to over-age the fish. Scales proved to be accurate only in younger fish. These findings could aid in the improvement of age determination accuracy for more species of fish as well as allow future technicians to age fish with much less training.

Introduction

Fish make up a large portion of the human diet. Fish are high in protein and low in fat, making them a healthy food choice as well as an important source of nutrition. Globally, fish make up 17% of the total animal protein consumption (Thilsted, 2013). Countries with high poverty rates often rely on the fishing industry because it is generally cheaper to buy fish than other sources of anprotein. In 2011, total fish production topped 154 million tons, with only 126 million tons being available for human consumption (Thilsted, 2013). Due to economic constraints, lack of knowledge, and improper fishery management, copious amounts of fish and fish products go to waste. While there are some who would argue that our planet's waters are a massive "storehouse" of fish and will never be depleted, it has been proven that overfishing has reduced recruitment (i.e. survival of juvenile individuals) in fish populations, especially in those with small population sizes (e.g. the Peruvian anchovy fishery collapse in 1972) (Hillborn, 2007; Hillborn and Walters, 1992; Myers *et al*., 1997). These reductions in recruits have prompted tighter regulations and increased interest in the management of economically important fish species.

Fisheries are an essential component of worldwide food and economic security. A fishery can be defined as an entity involved in the raising or harvesting of fish, both in the wild and on farms, and often includes a combination of fish and fishers within a region (Hart and Reynolds, 2002). Over time, it has become increasingly important for their management to be more sustainable to ensure continued productivity (Smith *et al*., 2012). Many fisheries experience stock collapse, or the depletion of stock levels to a critical point where recovery is impossible, indicating that we do not fully understand the complex mechanisms behind a fish species' population dynamics (Kerr *et al*., 2010; Wilson *et al*., 2009). Furthermore, successfully managing a fishery requires extensive knowledge of the mechanisms by which fish population abundance is regulated (Lorenzen and Enberg, 2001). At a local scale, fisheries require annual species-specific quotas to assess population sizes and health (Pauly *et al*., 2003). In the Great Lakes, specifically Lake Michigan, species that are large targets for fishing include whitefish (*Coregonus clupeaformis* Mitchill), yellow perch (*Perca flavescens* Mitchill), chinook salmon (*Oncorhynchus tshawytscha* Walbaum) and lake trout (*Salvelinus namaycush* Walbaum) (Goniea, 2014). With the exception of chinook salmon, which was introduced to the Great Lakes in 1967 to reduce the invasive alewife (*Alosa pseudoharengus* Wilson) population, all of these species are native to the Great Lakes and are threatened by invasive species as well as overfishing. It is critical to understand the interactions between natural and human threats, such as predator-prey interactions, overexploitation, and fish population stability in order to efficiently manage and regulate a fishery (Shelton *et al*., 2011).

Prior to the 1950's, Lake Michigan boasted the largest lake trout fishery in the world (Holey *et al*., 1995). Due to sea lamprey (*Petromyzon marinus* Linnaeus) predation and fishing overexploitation, the lake trout population was almost completely eliminated from the Great Lakes (Bronte *et al*., 2007). With increased regulations and careful management, the Michigan Department of Natural Resources (MDNR) has been trying to support the resurgence of lake trout populations by practicing stock enhancement (i.e. releasing hatchery lake trout into the wild)

(Madenjian, 2013). However, the hatchery fish have been struggling to reproduce naturally in the wild and their population remains in a relatively critical condition (Madenjian, 2013). It is common with stock enhancement strategies to observe unsatisfactory results, mainly due to the hatchery fish not performing well in the wild because of unintentional developmental and genetic adaptations to the hatchery environment (Lorenzen, 2005). As efforts increase to keep the lake trout populations stable, understanding their population dynamics is crucial. Lake trout prefer cold waters (7-12°C) and spawn in the fall (Ryan and Marshall, 1994). Their lifespan can reach 25 years of age, but they do not reach sexual maturity until the age of 6 or 7 (Ryan and Marshall, 1994). Thus, it is important to study the ages of individual fish to assess the health and success of the population as a whole.

Fisheries management requires a deep knowledge of species-specific growth regulations (e.g. density-dependent growth), population dynamics, and interactions with both natural and human factors (Lorenzen and Enberg, 2001; Shelton *et al.*, 2011). When a fishery conducts a population assessment (e.g. lake trout) an age class structure is often required to assess how long fish are living and if populations have a good balance of both young and old individuals. There are various methods of age determination, some being useful for many species of fish and others restricted to a few species. Each method comes with an element of error, usually due to an inadequate structure or age-reader subjectivity, both of which have lead to the overexploitation of populations (Campana, 2001). Therefore, it is imperative to utilize methods with the best proven accuracy.

Accurate age determination underlies all fisheries research, especially for fisheries raising economically important species, such as Californian anchovies (*Engraulis mordax* Girard), Atlantic salmon (*Salmo salar* Linnaeus), Atlantic cod (*Gadus morhua* Linnaeus), and lake trout (Ihde and Chittenden, 2002). Accurate age data of a population are the foundation for calculating that population's growth and mortality rates, recruitment, and stock structure, all of which are essential to sustainable management (Campana, 2001; Beverton and Holt, 1957). To determine the age of a fish, it is common practice to analyze calcified structures, such as scales and otoliths (small "stones" located within the inner ear of vertebrates), because they grow in periodic increments, called annuli, that can be physically measured (Campana, 2001). However, both structures are difficult to read, leading to error in age assessment. Otoliths have proven to be the most reliable source of age, but assessing them requires years of experience and is often considered an art form due to the level of difficulty. Scales are commonly used because they are easy to collect, although it is well known amongst fishery technicians that they are very inaccurate in determining age for larger, older fish (Morehouse *et al*., 2013). Finding alternatives to otolith and scale aging has grown in popularity due to outside factors (e.g. increasing water temperature and toxins from fertilizer runoff) affecting the annuli seen in scales and the opaque zones seen in otoliths (Morehouse, *et al*., 2013). Additionally, the usefulness of calcified structures for age determination can vary geographically, making it difficult to find a structure that is reliable for many species (Beamish and McFarlane, 1983). Tag-recapture efforts, involving injecting live fish with a magnetic coded wire tag (CWT), have also been utilized, however it is difficult to ensure the capture of enough of these fish for the purposes of age studies.

Although otoliths have been proven to be the most accurate age determination method available, their extraction requires killing the fish, which can be harmful to populations already under pressure from overfishing and invasive species. As a result, many fisheries have increased their efforts to discover a non-lethal method. Current research projects include the study of pectoral fin ray and dorsal fin spine clips, both of which cause the fish minimal stress (Morehouse, *et al*., 2013). One such study found the dorsal fin spine clips to be much more accurate than otoliths in the age determination of Colorado pikeminnow (*Ptychocheilus lucius* Girard) (Hawkins *et al*., 2004).

However, to our knowledge, only one study has measured the maxillary bone, or the upper jaw, as a method of age determination. This study found that maxillae provide an equally accurate method of aging Lake Huron lake trout as the otolith, but with much less technician training and experience required (Wellenkamp and He (unpublished), 2014). Although extracting the maxillary bone is currently lethal, increased research efforts could uncover a technique to extract a section of it for assessment without causing significant harm to the fish. The purpose of this study was to compare the age determination accuracy of Lake Michigan lake trout maxillae to that of scales and otoliths and use the results to encourage fisheries to consider seeking alternative methods as well. The goal is to spark more research on the maxilla so that it can eventually evolve into a non-lethal method of aging lake trout, as well as other species populations that would benefit from non-lethal age determination.

Materials and Methods

Sample Collection

I conducted my research from June to September 2014 at the Michigan Department of Natural Resources (MDNR) Charlevoix Fisheries Station in Charlevoix, Michigan. Lake trout samples were collected along the eastern shore of Lake Michigan, beginning 2014 May 5 and ending 2014 June 26 in accordance with the assessments designated by the Lake Wide Assessment Plan (LWAP) (Schneeberger *et al*., 1998). Collection locations were determined according to the agreed upon specifications in the LWAP by MDNR. Fish were caught using bottom gill nets on the Station Vessel (S.V.) Steelhead at depths of 15, 30, and 50 meters in varying regions of Lake Michigan (Figure 1). After capture, fish were sorted into mesh bags by net identification number and fish number and placed in coolers containing ice for later examination. All information regarding each individual fish, including sex, length (mm), weight (g), and fin clip (if present) was recorded into the MDNR 2014 Survey Vessel database.

Extraction of sample structures took place during fish examination on board the survey vessel. Otoliths were extracted from fish over 650 mm in length by making a deep cut into the head of the fish directly behind the eyes down to the upper edge of the gills using a large, sharp knife. The head was opened by pressing down on the nose, at which point the otoliths, located directly behind the brain (Nielsen and Johnson, 1983), were removed using small forceps. Scales were removed by scraping a knife against the side of the fish, slightly behind the dorsal fin, in the opposite direction of growth (e.g. from the tail towards the head). Maxillae were removed by peeling back the upper lip and extracting the upper jaw using a sharp knife that cut away the bone from the mouth. All structures were placed in dry envelopes labeled with their respective fish and net identification numbers and allowed to air-dry to constant weight.

Heads were collected from fish that contained an adipose (AD) fin clip, which indicated that they possess a coded wire tag (CWT) (i.e. a small magnetic wire imprinted with microscopic numbers). Until recently, fin clips were utilized for determining the age of hatchery fish (J. Jonas, personal communication, July 31, 2014). Unique fin clips were made on all hatchery fish released in a given year, with the type of fin clip rotating from year to year. CWTs have since begun to replace the fin clip method. Fish with CWTs are considered to be known-age fish because the codes correspond to the specific year in which they were placed, allowing us to be certain of the age of the fish. Heads were stored in Ziploc® bags labeled with identification numbers as previously mentioned and stored in coolers of ice.

Subsample Determination

While the Michigan DNR Survey Vessel collected thousands of fish samples, not all of them were suitable for the purposes of this study. In order to give evidence of maxilla accuracy, we need to be certain of the true age of the fish. Therefore, all fish with an AD clip, thus containing a CWT, were used in this study because they are known-age fish. Our original goal was to analyze structures from 100 fish in each length category, ranging from 100 mm to 1000 mm, in order to achieve an even distribution of ages. However, the AD fish collected did not provide a large enough sample size nor an even length distribution to fit this parameter (Table I). Gaps in the number of fish per length category were filled with fish that possessed a fin clip which could be traced back to the year it was made, therefore telling us an approximate true age of the fish (Table II). Fish with an AD clip represented small clusters of age groups with large gaps between years (Table III), whereas clip fish contained a wide spectrum of ages and thus a more evenly distributed data set (Table IV).

Structure Processing

In order to determine an age from the collected scales, otoliths, and maxillae, they first needed to be processed and imaged. Scales were taken from the labeled envelopes using forceps and placed in hand, where a few drops of distilled water were added. I used my index finger to rub the scales across my palm to separate the clumps and to clean off debris. One to three scales were then placed on a glass slide under a Nikon microscope (Nikon Corporation, Tokyo, Japan) to be imaged. This step needed to be done quickly before the scale dried out and began to curl. Only scales without blown out centers (e.g. scales with circuli only present at the outer edge), which indicates the scale replaced one that was lost and had to grow rapidly, were imaged using a Nikon SM2100 (Nikon Corporation, Tokyo, Japan) set at 2x power with a 1x lens (Figure 2).

Otoliths were processed using the "crack and burn method" (Edwards *et al.*, 2011). Using small forceps, the larger of the two otoliths was removed from the envelope and cleaned of any debris. It was then gripped with a large pair of forceps and oriented such that the rounded lobe faced down, as this is the area to be filed, and the tip of the forceps was placed in the middle of the two lobes. Using my index finger to hold the otolith in place, it was filed until smooth using a Woodcraft water stone grinder (RPM 420) (Woodcraft, Grand Rapids, Michigan, USA, Model 144846). With the tips of curved forceps pointing in the same direction as the sharp end of the otolith, the filed end of the otolith was then burned using a Coleman® portable propane camp stove (Coleman, Wichita, Kansas, USA) at low heat. Otoliths were held near the flame until browned (approximately 7 seconds). It was then allowed to cool for about one minute. Using the curved forceps, I placed the otolith in a capful of white clay, with the non-burned edge oriented down, and a drop of mineral oil was added to the filed edge to enhance visualization of annuli. Images were taken using the same image system as the scales at the same power (Figure 2).

Maxillae were cleaned as much as possible of any fat and skin remnants using large forceps. They were then placed on a custom-made cutting board set up parallel to a mounted Dremel rotary cutting tool (Dremel, Mount Prospect, Illinois, USA, Model 395 Type 5). Damascus Separating Discs, or silicon carbide cutting discs (22.2 mm x 0.127 mm), were used as blades. Maxillae were placed on the cutting board with the distal end towards the blade and sawed into thin, parallel slices (approximately 0.1 mm) starting at the third or fourth tooth. A Woodworker's Portable Dust Collector served as a vacuum to collect dust. Three or four slices were cut and then dipped in mineral oil to enhance annuli visualization. Slices were then imaged using the same imaging system as described above for scales and otoliths at the same power (Figure 2).

Aging

I used the Preview application on my MacBook Pro® computer (Apple Inc., Cupertino, California, USA) to view the images of each structure for age determination. Scales contain dark ridges, called circuli, that are laid down throughout the lifespan of the fish. Several circuli are added each year, with slower growth during winter months placing them closer together (Nielsen and Johnson, 1983). The outermost edge of a pack of rings indicates the end of that year's growth and is called an annulus. Counting the number of annuli within a scale determines the age of the fish (Nielsen and Johnson, 1983).

Otoliths form annuli in a similar manner as scales, with dark bands indicating months of slow growth during the winter and opaque bands indicating months of fast growth during the summer. A dark and opaque band together indicate one year of growth (Nielsen and Johnson, 1983). Age is determined from an otolith by counting the number of annuli (the dark bands) outwards from the first band visible outside of the nucleus or center (Nielsen and Johnson, 1983). I also counted the outermost edge of the otoliths because the fish were caught during the spring and were thus actively growing before collection.

Maxillae are similar to scales and otoliths in that they also form annuli that are concentric around a central focus, however they appear as bright bands within dark areas. The focus represents age 0 and was not counted (Nielson and Johnson, 1983). Light bands were counted outwardly from the focus by tracing the band fully around the center to ensure it was not a false annulus. I also included the outer edge due to the spring collection time.

CWT Extraction and Reading

All heads that had been collected from AD fish were kept in a large freezer for several days. Heads from each collection location were removed from the freezer and allowed to thaw for approximately 30 minutes. Using a large knife, bags were cut open and the heads removed and placed on a large plastic cutting board. I used a serrated knife to cut the head completely in half between the eyes. A magnet detector was used to determine which half contained the CWT. The half containing the CWT was dissected until the CWT was located. The CWTs were extracted with a thin magnet and placed on paper next to corresponding identification numbers, where it was taped using thin strips of Post It tape.

After extraction, all CWTs were individually read on a microscope connected to a small television for optimal visualization (Figure 3). Codes were recorded next to the identification numbers and CWTs were replaced for storage. All codes were entered into the MDNR Charlevoix Fisheries Database and matched with their respective ages for later data analysis.

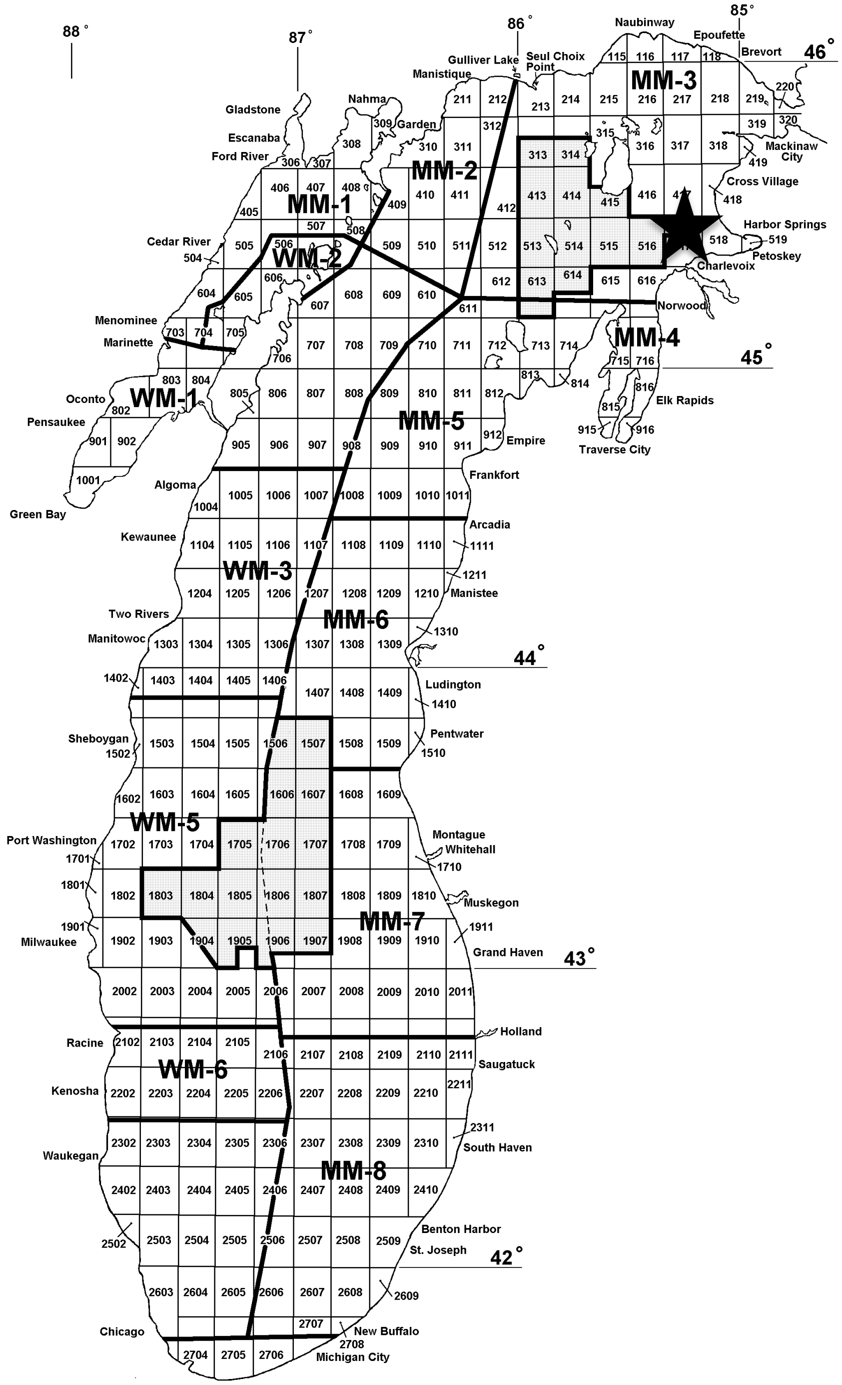

Figure 1. Lake Michigan districts as decided by the Lake Wide Assessment Plan. The 2014 lake trout (*Salvelinus namaycush*) survey was conducted in districts MM-3, MM-5, MM-6, MM-7, and MM-8. The star indicates the location of this study. The shaded areas were used for a separate purpose and do not apply to this study.

Table I. Total number of adipose fin clip fish structures in each length category.

Tag Data			
Length Category (mm)	Maxillary Frequency	Otolith Frequency	Scale Frequency
100	0	0	0
200	0	0	0
300	9	0	9
400	55	0	55
500	113	0	113
600	92	0	91
700	19	5	19
800	2	2	2
900	0	0	0
1000	0	0	0
Total	290	7	289

Table II. Total number of clipped fish structures in each length category.

Clip Data			
Length Category (mm)	Maxillary Frequency	Otolith Frequency	Scale Frequency
100	0	0	0
200	0	0	0
300	0	0	0
400	5	0	5
500	0	0	0
600	9	0	9
700	76	48	74
800	90	87	89
900	18	18	18
1000	1	0	1
Total	199	153	196

Table III. Distribution of ages obtained from structures that matched true age of adipose fin clipped fish.

	Number of Samples		
True Age	Maxilla	Otoliths	Scales
1	--	--	--
2	20	--	20
3	72	--	72
4	190	2	189
5	6	3	6
6	--	--	--
7	--	--	--
8	--	--	--
9	--	--	--
10	--	--	--
11	1	1	1
12	--	--	--
13	1	1	1
Total	290	7	289

Table IV. Distribution of ages obtained from structures that matched true age of clipped fish.

	Number of Samples		
Clip Age	Maxilla	Otolith	Scale
5	22	8	22
6	33	18	32
7	14	9	14
8	41	38	41
9	16	11	16
10	20	20	20
11	17	15	17
12	16	15	15
13	8	7	7
14	7	7	7
15	5	5	5
Total	199	153	196

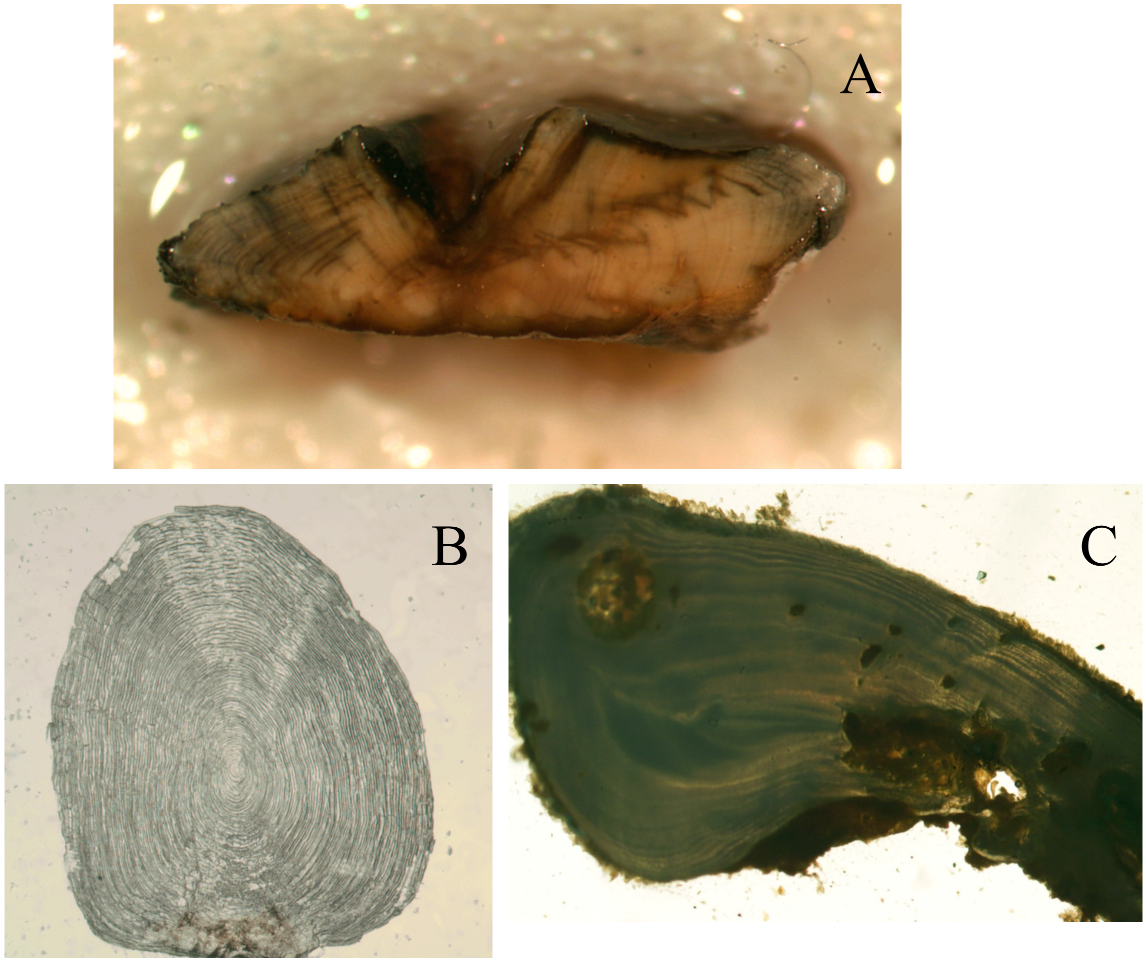

Figure 2. Processed lake trout structures from the same fish at 2x power. A) Otolith aged at 15 years. B) Scale aged at 11 years. C) Maxilla aged at 15 years.

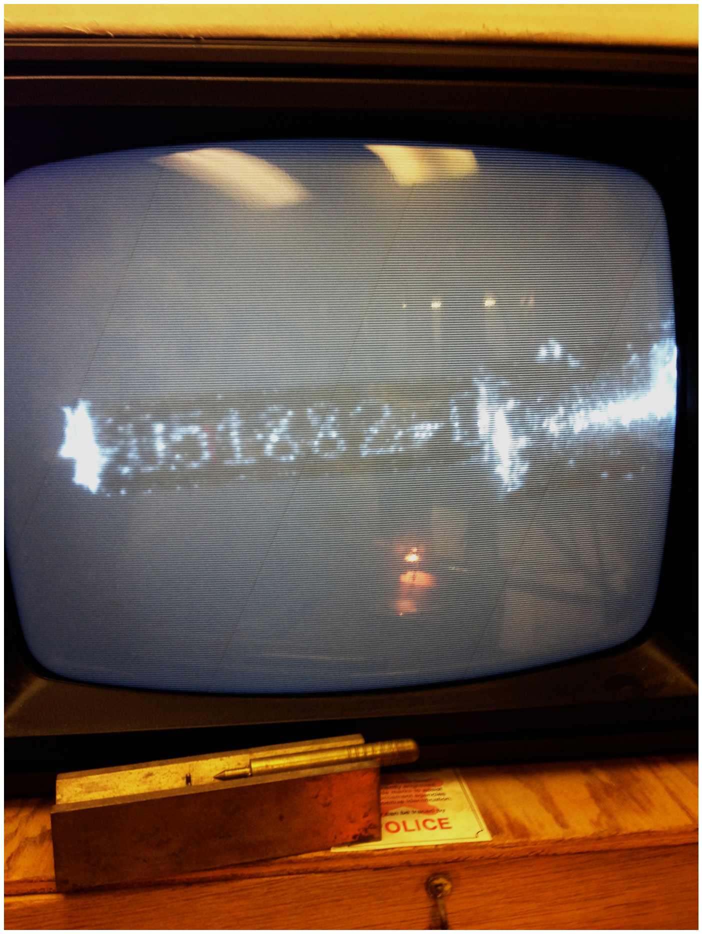

Figure 3. Coded wire tag under a microscope connected to a television. The code corresponds to the specific year in which it was injected into the fish. The brass tool is the magnet used to handle coded wire tags.

Results

The maxilla proved to be the most accurate structure for age determination in Lake Michigan lake trout. While all three structures possessed an element of error in determining ages, the ages obtained from the maxillae generally had lower deviations from true age than otoliths and scales.

The maxillae gave ages that were close to the true ages for almost all age classes (Figure 4A). The maxillae ages agreed with true ages within ± 1 year in 22.6% of the clipped samples and within ± 1 year in 14.8% of the AD samples, all of which were under the age of 8 years old (Table V). They were also relatively accurate at determining ages for younger fish (i.e. 2-3 years old), with only 3.1% of the maxillae ages being >2 years from the true age for AD samples (Table VIII).

Otoliths usually gave ages much higher than the true ages (Figure 4B). They considerably over-aged younger fish, with 41.8% of the obtained ages being >2 years from the true ages in the 5-8 year old clipped samples (Table VI). They were relatively accurate with older fish, with 15% of obtained ages being ± 1 year from true ages in the 9-15 year old clipped samples and 14.3% being ± 1 year from true ages in 4-13 year old AD samples (Table VI, IX).

Ages obtained from scales were consistently lower than the true ages (Figure 4C). While they were more accurate in determining ages for younger fish (up to 8 years of age), as 20% of obtained ages were within ± 1 year of true age in clipped samples, they severely under-aged older fish (9 years of age and up), as 15.8% of obtained ages being >2 years from true ages in clipped samples (Table VII, Table X).

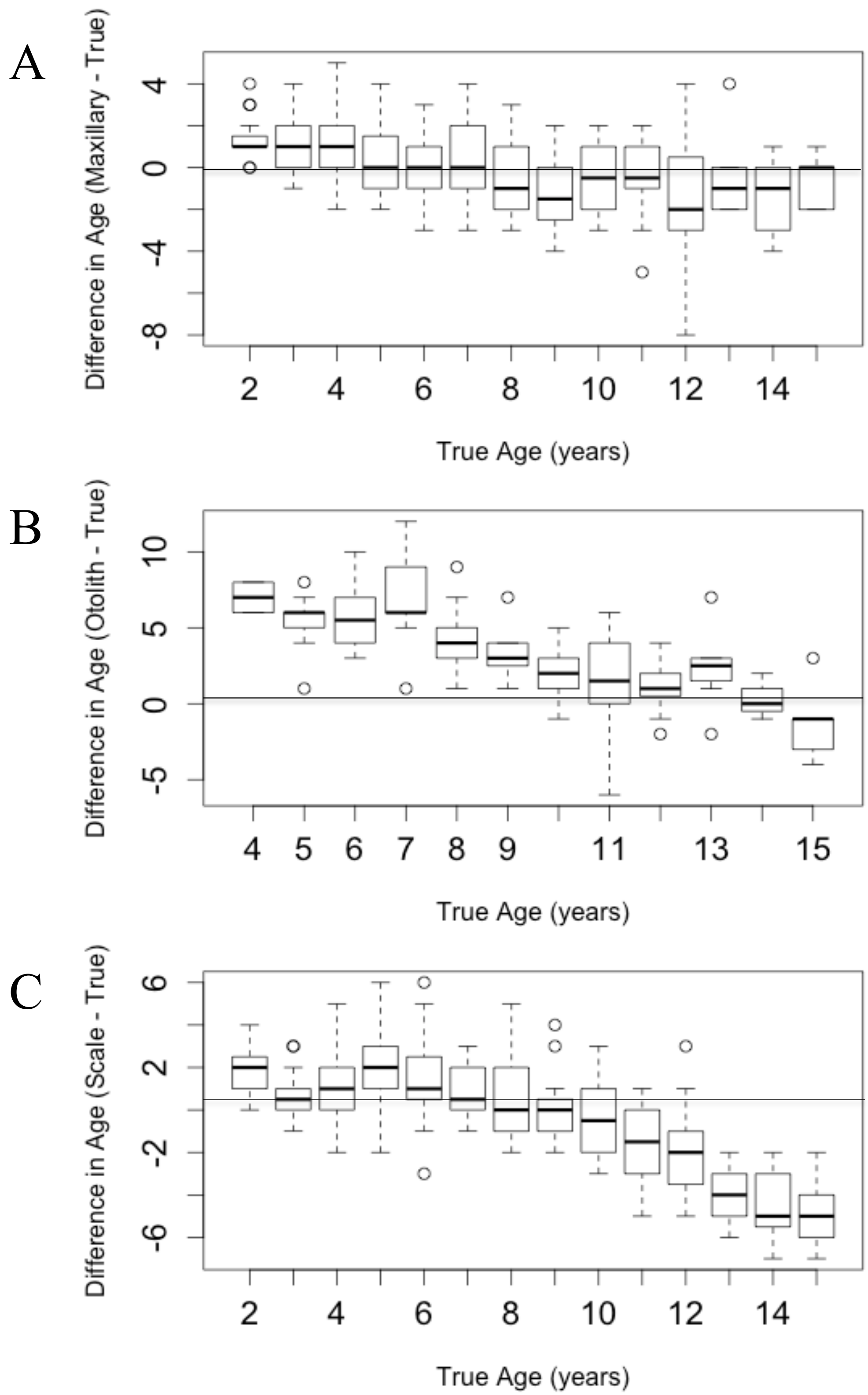

Figure 4. Deviations of estimated ages from true ages. A) Deviations of ages obtained from maxillae from true ages. B) Deviations of ages obtained from otoliths from true ages. C) Deviations of ages obtained from scales from true ages.

Table V. Percentage agreement between ages obtained from maxillae and true ages based on fin clip.

Maxillary Percent Agreement for Clip Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
5-8	111	12.6%	22.6%	14.6%	5.5%	55%
9-15	87	8.5%	13.6%	12.1%	10.6%	45%
Total	199	--	--	--	--	100%

Table VI. Percentage agreement between ages obtained from otoliths and true ages based on fin clip.

Otolith Percent Agreement for Clip Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
5-8	73	0%	2%	4%	41.8%	47.8%
9-15	80	4.6%	15%	13.1%	19.6%	52.3%
Total	153	--	--	--	--	100%

Table VII. Percentage agreement between ages obtained from scales and true ages based on fin clip.

Scale Percent Agreement for Clip Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
5-8	109	9.2%	20%	13.8%	12.8%	55.8%
9-15	87	6.1%	11.2%	11.2%	15.8%	44.3%
Total	196	--	--	--	--	100%

Table VIII. Percentage agreement between ages obtained from maxillae and true ages based on coded wire tags obtained from adipose fin clipped fish.

Maxillary Percent Agreement for AD Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
2-3	93	7.6%	14.8%	6.2%	3.1%	31.7%
4-13	197	10.7%	29%	13.4%	15.2%	68.3%
Total	290	--	--	--	--	100%

Table IX. Percentage agreement between ages obtained from otoliths and true ages based on coded wire tags obtained from adipose fin clipped fish.

Otolith Percent Agreement for AD Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
2-3	0	0%	0%	0%	0%	0%
4-13	7	0%	14.3%	0%	85.7%	100%
Total	7	--	--	--	--	100%

Table X. Percentage agreement between ages obtained from scales and true ages based on coded wire tags obtained from adipose fin clipped fish.

Scale Percent Agreement for AD Age						
True Age Range	Sample Size	±0	±1	±2	>2	Total
2-3	92	10.7%	21.1%	6.6%	2.4%	31.8%
4-13	197	14.2%	28%	18%	8%	68.2%
Total	289	--	--	--	--	100%

Discussion

Overall, maxillae were consistently more accurate in age determination than otoliths and scales. The ages obtained from them were consistently closer to the true age of the fish in both younger and older individuals. The annuli present within the maxillae were often very visible and distinct, making it much easier to count how many had formed during the life of the fish. Otoliths, on the other hand, severely over-aged young fish but were relatively accurate with older fish. In order for the annuli in otoliths to be visible, the structure had to be burned. An otolith that was not burned enough or burned too much would be very difficult to read and would thus affect the reader's capability of accurately determining an age. Scales were accurate in determining ages for fish up to eight years old, but greatly under-aged older fish. The annuli on scales are not nearly as distinct as those on maxillae and otoliths, so visualizing and counting them becomes increasingly difficult with fish age.

Precise information regarding population age structure is crucial to the proper and sustainable management of threatened fish species. Utilizing reliable calcified structures for age determination allows for exact calculations of population extinction risk as well as educated decisions on how to best protect a species (Price *et al*., 2014). The use of inaccurate age estimation in fisheries management can contribute to stock collapse due to errors in stock metrics (e.g. recruitment, growth and mortality rates) that will exacerbate problems already occurring due to overfishing and climate change (Rude *et al*., 2013). The use of scales for age determination has been on the decline as more and more studies show their inaccuracy in assigning age to fish over the age of five years old (Morehouse *et al*., 2013; Rude *et al*., 2013; Hawkins *et al*., 2004). A study conducted on age determination for smallmouth bass (*Micropterus dolomieu* Lacépède) showed that scales consistently under-aged individuals in comparison to otoliths (Rude *et al*., 2013). The otolith is the favored structure among many fish biologists for use in age determination studies (Beckman, 2002). However, the concurrent opaque zones that are believed to form during increased rates of growth could also be due to temperature changes during the summer months, and are thus not a completely reliable source of age (Beckman and Wilson, 1995).

With the uncertainty that comes with the two most common structures used for age determination, more research is being conducted to discover new, more reliable methods. Recent studies have explored the possibility of using pectoral fin rays and dorsal fin spines as nonlethal methods for age determination, but none yielded results that could displace the otolith as the most accurate structure (Morehouse *et al*., 2013; Rude *et* al., 2013; Idhe and Chittenden, 2002). Idhe and Chittenden (2002) examined the reliability of sectioned pectoral fin rays and dorsal fin spines. They found the pectoral fin rays to be too small to confidently read, while the dorsal fin spines were much more reliable and contained prominent growth marks. However, both structures contain vascular cores that obscure early growth marks. To my knowledge, only one other study, conducted in Alpena, Michigan, has investigated the maxilla as method of age determination (Wellenkamp and He, 2014, unpublished).

While Wellenkamp and He's (unpublished; 2014) study was the first to test the accuracy of lake trout maxillae age determination, it did not compare that accuracy to that of other calcified structures used for age determination. Instead, it only compared the ages obtained from maxillae to the true ages of the fish from which they were collected. They found maxillae ages to agree with true ages within ± 2 years in 94-95% of their 83 known-age fish. As the method further developed, they were able to accurately age fish up to 24 years old. My study further supported the accuracy of maxillae age determination by comparing it to that of otoliths and scales, and finding it to be more consistently accurate across age groups, whereas otoliths favored older fish and scales favored younger.

In contrast, Wellenkamp and He’s study focused on Lake Huron lake trout, whereas this study focused on Lake Michigan lake trout. Surprisingly, there are large differences between the two populations. Lake Huron lake trout populations have remained quite small, yet they live to much older ages. Lake Michigan lake trout populations are more abundant but the vast majority of fish originated in hatcheries and do not live as long as Lake Huron lake trout (J. Jonas, personal communication, July 31, 2014). Furthermore, maxillae sections taken from Lake Huron fish showed annuli up into the tooth which aided technicians with age determination. I did not find cutting along a tooth in Lake Michigan lake trout maxillae to be useful for age determination, as there were no distinguishable annuli located there. Despite these differences, both studies gave supporting evidence that using maxillae is as accurate, if not more accurate, at determining ages for lake trout as the otolith.

In conclusion, the maxilla is a viable method for the age determination of Lake Michigan lake trout. The extraction of the maxilla is a much quicker and easier process than the extraction of otoliths, and thus would save precious time during the annual surveys in the spring. Additionally, much less training and experience is required for lab technicians to accurately determine age from a maxilla section in comparison to otoliths, which takes years of experience and dedication. Scales are rarely, if ever, used to determine ages for larger and older fish, so maxillae could completely displace them as an age determination structure. Future directions could include maxillae studies on different species of freshwater fish. With more investigation into the practicality of maxillae, it is possible that a non-lethal technique could be discovered and perfected to develop an accurate and more conservation-based age determination method. Currently, very few fisheries utilize non-lethal methods, such as fin rays and dorsal fin spines, due to their level of inaccuracy in age determination (Maceina *et al*., 2007). Discovering a way to extract a portion of the maxilla with minimal stress to the fish would allow fisheries to conduct age assessments on threatened populations without causing further harm to their recovery. Therefore, the maxilla should be utilized to the furthest degree in order to enhance current age determination studies to a new level of efficiency while also conserving fish species and aiding in the movement towards sustainable fishery management.

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